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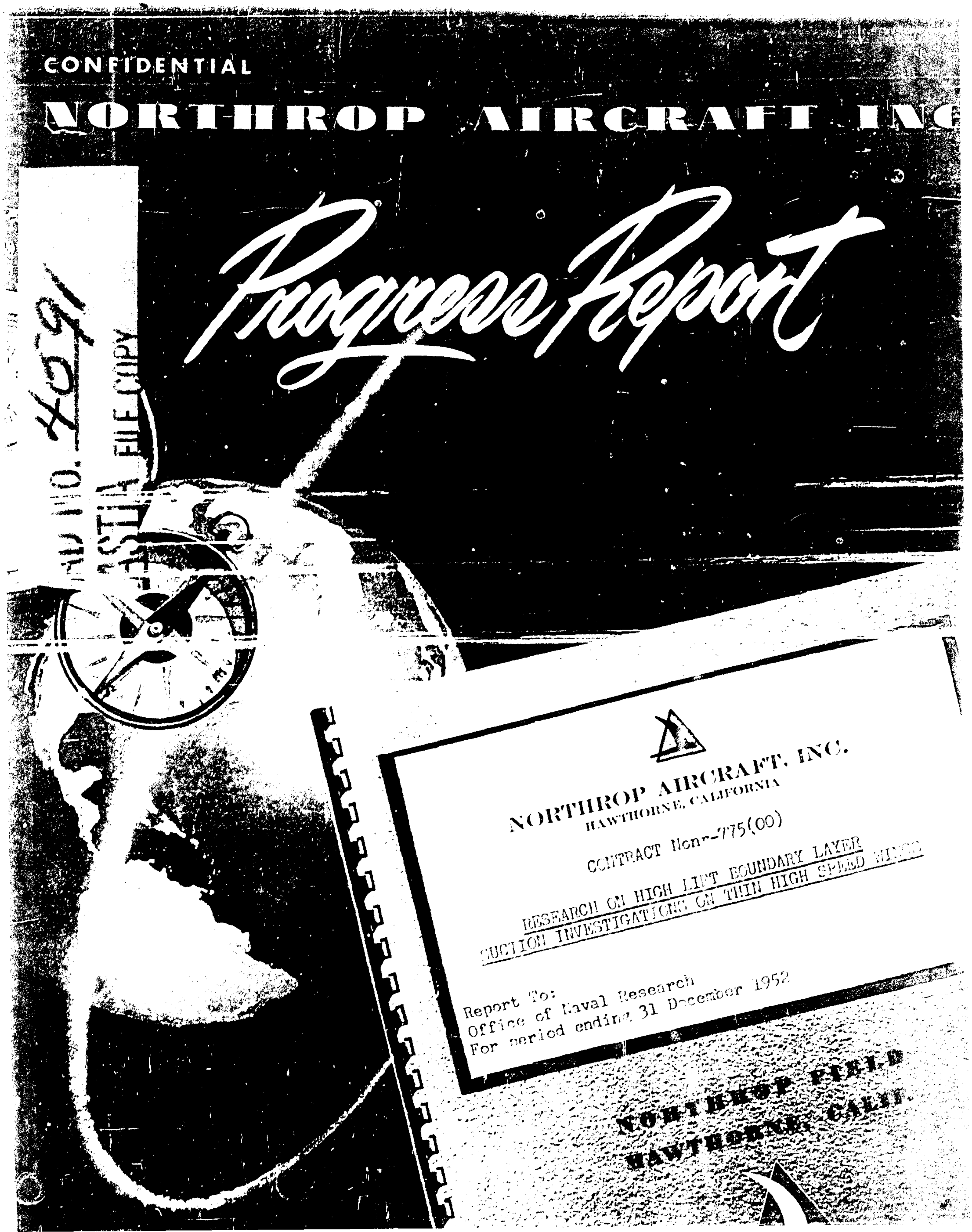

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NORTHROP AIRCRAFT INC
Progress Report
AD NO. 4091
ASTIA FILE COPY
NORTHROP AIRCRAFT, INC.
HAWTHORNE, CALIFORNIA
CONTRACT Nonr-775(00)
RESEARCH ON HIGH LIFT BOUNDARY LAYER
SUCTION INVESTIGATIONS ON THIN HIGH SPEED
Report To:
Office of Naval Research
For period ending 31 December 1952
NORTHROP FIELD
HAWTHORNE, CALIF.

SECURITY INFORMATION **CONFIDENTIAL**

PROGRESS REPORT

NORTHROP AIRCRAFT, INC.

HAWTHORNE, CALIFORNIA

CONTRACT Nonr-775(00)

Report To:

OFFICE OF NAVAL RESEARCH

For Period Ending 31 December 1952

Prepared By:

BOUNDARY LAYER RESEARCH PROJECTS OFFICE

CONFIDENTIAL

SECURITY INFORMATION CONFIDENTIAL

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NORTHROP AIRCRAFT, INC.

PROGRESS REPORT - RESEARCH ON HIGH LIFT BOUNDARY LAYER SUCTION INVESTIGATIONS ON THIN HIGH SPEED WINGS

CONTRACT Nonr-775(00)

I. BRIEF OF CONTRACT

A. Financial:

Estimated Contract Value	$74,719
Expenditure to 12-21-52	42,590
Unexpended Balance	$32,129

B. Basic Contract:

Supply the necessary personnel and facilities for, and in accordance with, any instructions issued by the Scientific Officer or his authorized representative; conduct research on high lift boundary layer and circulation suction calculations and experiments with thin swept wings.

II. TECHNICAL PROGRESS

A. Theoretical Investigations

The purpose of the present contract is the investigation of high lift boundary layer control (suction and blowing) on thin high speed wings, preferably with sweepback.

In order to understand how best to apply boundary layer control on a high lift suction wing, it is desirable to know the pressure and velocity distribution on the upper wing surface. Since the non-separated flow with boundary layer suction differs only slightly from potential flow, calculation of the velocity distribution over high lift suction airfoils for potential flow is justified, for example, with Theodorsen's method.

The velocity distributions along the chord (2-dimensional, potential flow) have been calculated for various wing sections and flap combinations at different angles of attack:

Case I	NACA 0006-64	(40° L.E. Flap @ 15 % c &) (40° T.E. Flap @ 30 % c)
Case II	NACA 0006-64	(40° T.E. Flap @ 30 % c)
Case III	NACA 0006-64	(40° T.E. Flap @ 30 % c) (Modification I)
Case IV	NACA 0006-64	(40° T.E. Flap @ 30 % c) (Modification II)
Case V	NACA 0006-64 Compared with Modification I and Modification II	(40° T.E. Flap @ 30 % c)
Case VI	NACA 0006-64	(60° L.E. Flap @ 15 % c &) (60° T.E. Flap @ 30 % c)
Case VII	NACA 0006-64	(60° L.E. Flap @ 15 % c &) (60° T.E. Flap @ 30 % c) (With Plate)
Case VIII	Comparison of Data from Case VI and Case VII	
Case IX	NACA 0006-64	(60° T.E. Flap @ 30 % c)

Case X	NACA 0006-64	(40° L.E. Flap @ 15 % c &) (40° T.E. Flap @ 30 % c +) (30° T.E. Flap @ 10 % c)
Case XI	NACA 0006-64	(40° T.E. Flap @ 30 % c +) (30° T.E. Flap @ 10 % c)
Case XII	NACA 0006-64	(60° Kruger Flap and) (60° T.E. Flap @ 30 % c)
Case XIII	NACA 0006-64	(60° Kruger Flap, Modified &) (60° T.E. Flap @ 30 % c)
Case XIV	NACA 66-006	(40° T. E. Flap @ 30 % c)
Case XV	NACA 0004-64	(40° L.E. Flap @ 15 % c &) (40° T.E. Flap @ 30 % c)
Case XVI	NACA 0004-64	(40° T.E. Flap @ 30 % c)
Case XVII	NACA 0009-64	(40° L.E. Flap @ 15 % c &) (40° T.E. Flap @ 30 % c)

Additional potential flow calculations are intended on [illegible] extremely thin high speed sections with deflected leading and trailing edge flap. A report describing the results of these calculations is being completed.

With the knowledge of the chordwise velocity distribution, it is possible to estimate the boundary layer development and to determine the most efficient method of boundary layer control. Boundary layer suction, preferably, should be applied in the region of the pressure rise downstream of minimum pressure peaks. At high lift coefficients, high negative pressure peaks develop on the upper surface close to the leading edge and in the regions of the hinge line of the [illegible] and trailing edge flaps.

In order to estimate optimum location of [illegible] and the suction quantities, it is desirable to know the boundary layer development along the chord. Such calculations have been [illegible] the NACA 0006-64 airfoil with 40° deflected 0.30 c trailing edge flap [illegible] with and without 40° deflected 0.15 c leading edge flap [illegible] leading edge flap, suction was assumed at the hinge line [illegible]

with a turbulent boundary layer at these stations. Without a deflected leading edge flap, suction will preferably be applied on the upper surface close to the leading edge and at the rear hinge line. Leading edge suction will delay leading edge separation. Calculations of the laminar boundary layer development with suction close to the leading edge of a 0006-64 section with 40° deflected trailing edge flap indicate that very small suction quantities ($C_Q \cong 0.0001 - 0.0002$) should be sufficient to avoid leading edge separation up to $C_L \cong 2.8$ (2-dimensional). These calculations were conducted at Northrop Aircraft, Inc. on I.B.M. equipment. High lift suction experiments at NACA (Ames) on an F-86 have shown that a considerably larger suction quantity ($C_Q \cong 0.001$) and power than laminar flow theory indicates were required to avoid leading edge separation. Since leading edge suction would become much more attractive with the theoretical suction quantities with laminar flow in the suction region, some time was spent in attempting to explain the discrepancy between theory and experiment. Premature transition in the suction region might have resulted from the relatively large surface roughness (very thin laminar boundary layers) and waviness of the porous surface at the F-86 leading edge or from the effect of spanwise flow on transition. It is intended to calculate the spanwise laminar flow with continuous suction at the leading edge of a 0006-64 section at high C_L. Also, some basic laminar suction experiments at the leading edge of a high lift suction wing are contemplated in order to verify the theory. These experiments should preferably be conducted in full size. In order to investigate the effect of spanwise flow, the tests should be repeated with sweepback. Since a smoother wing surface (roughness and waviness) seems more possible with suction through several fine slots rather than through a porous surface, emphasis will be placed on suction through several slots.

The calculation of the turbulent boundary layer development along the chord of the NACA 0006-64 section with deflected trailing edge flap indicates that relatively weak suction at the flap hinge line should be sufficient to avoid turbulent separation at the trailing edge. With a single slot slightly downstream of the hinge line of the trailing edge flap, values of $C_Q \cong 0.005$ should insure attached flow [illegible] 60° deflected trailing edge flap. Smaller suction quantities [illegible]ould basically be possible with distributed suction in the region [illegible] rear hinge line than are possible with a single slot, since the [illegible]tion of the boundary layer momentum thickness per unit suction [illegible] is most favorable by sucking away only the innermost slowest [illegible] boundary layer close to the surface (distributed suction).

[illegible]his reason, particular emphasis should be given to [illegible]on in the region of the flap hinges. Distributed [illegible]chieved by suction through a porous surface and can be [illegible] suction through a larger number of fine slots. In the [illegible] smoother wing surface and a smaller pressure drop through

the suction surface are more possible than with a porous surface.

With single slots the suction power can be reduced by recovering part of the kinetic energy of the suction air in a slot diffusor. Preliminary slot diffusor experiments have been conducted and will be continued at Northrop. Pressure recovery factors of 80% have been obtained.

Boundary layer calculations on other thin high lift suction airfoils will be continued.

From the previous theoretical studies on thin high lift suction wings the following conclusions can be drawn: From the standpoint of high lift, it is advantageous to deflect a leading and trailing edge flap approximately 60^{o} and to apply boundary layer suction in the region of the hinge line. Suction through a larger number of fine slots or through a porous surface will require smaller suction quantities and slightly less power than with a single slot. Somewhat smaller $C_{L\ max}$ will be possible without a deflected leading edge flap and with laminar suction close to the leading edge. On straight wings, $C_{L\ max}$ will be possible without a deflected leading edge flap and with laminar suction close to the leading edge. On straight wings, $C_{L\ max}$ will then be limited by compressibility.

A Krüger flap together with suction at the leading edge may give slightly higher $C_{L\ max}$ than a deflected leading edge flap. An additional increase in $C_{L\ max}$ should result from a double deflected trailing edge flap, with suction at both hinge lines or with a combination of suction at the front and blowing at the rear hinge line.

From the standpoint of power, suction seems to be more favorable than blowing. However, blowing is often less complicated and less sensitive than suction.

On swept wings the flow component normal to the wing is essentially important for lift. In this manner C_L on a swept wing can be estimated to some extent from equivalent straight wings. However, spanwise flow effects considerably affect the high lift behavior of swept wings.

B. <u>Experimental Investigations</u>

In order to verify the theoretical expectations, a thin straight and somewhat thicker swept half span high lift suction model will be designed, built and tested. Particular emphasis will be given

to the swept model. Full span leading edge flaps and 0.30 c trailing edge flaps will be installed. Suction will be applied in the region of the flap hinge lines and emphasis will be given especially to distributed suction in this region (several fine slots).

The following combinations will be investigated experimentally:

a) Suction at the front hinge line (0.15 c) over whole span; suction at rear hinge line (0.70 c) over whole span; deflected leading and trailing edge flaps

b) Suction at 0.15 c over whole span; suction at 0.70 c over inner part of the wing, blowing over outer part of the wing at 0.70 c; deflected leading and trailing edge flaps

c) Suction at 0.15 c over whole span; suction at 0.70 c over whole span; blowing at 0.90 c over whole span; deflected leading and trailing edge and at the rear hinge line

d) Wing without deflected leading edge flap; suction at the leading edge and at the rear hinge line.

Model design studies on a 5%-thick straight and a 7%-thick swept wing model have been conducted. It is intended to design and build the models in a manner in which the combinations a) through d) above can be investigated with a minimum number of models.

Fabrication of the above mentioned high lift suction wing models has not as yet been started.

It is intended to run preliminary suction experiments at the Northrop tunnel (8 x 12 ft cross section) in order to thoroughly check the whole experimental setup before conducting the final suction experiments at the David Taylor Basin.

III. PHYSICAL COMPLETION

	Estimated Weight Factor	Estimated Percent Complete	Estimated Physical Completion
Theoretical Investigations	40	85	34
Model Design	20	70	14
Model Fabrication	20	0	0
Experimental Investigation	20	5	1
	100%		49%